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CHAPTER 9

HIGHWAY DESIGN

9.1 GENERAL

This Chapter provides policies, procedures and methods for developing and documenting the design of highways. It also includes the preparation of plans, specifications and estimates (PS&E) for new highway construction, reconstruction and RRR (Resurfacing, Restoration and Rehabilitation) improvements.

9.1.1 Role of the Designer

The designer shall gather all of the engineering and environmental input required to develop the design and provide a complete and acceptable PS&E assembly. The PS&E package represents the design and depicts the commitments made during the planning, programming and project development stages.

The designer is responsible for applying guidance from Chapter 8 and Chapter 9. In addition, the following Chapters provide information on collecting background data for the development of the design and PS&E:

1. **Chapter 2, Planning and Programming.** The information in Chapter Two presents planning and programming functions, interagency agreements and general data on the scope and funding levels for individual projects are covered in this chapter.

2. **Chapter 3, Environment.** Chapter Three provides information about environmental requirements and public involvement. Environmental documents will include commitments made for mitigation and public acceptance of the project. The designer will review all environmental documents for commitments made during the conceptual studies phase that affect development and construction of the project or operation of the highway following construction. Any proposed deviation from the mitigating measures and commitments must be coordinated with the Environmental Division and affected resource agencies.

3. **Chapter 4, Conceptual Studies.** Chapter Four presents a discussion on conceptual studies, which result in a recommended roadway location and basic design criteria for a facility. These studies are generally developed in conjunction with the environmental process. Conceptual studies generally include significant input from the owner agency and from other interested parties.

4. **Chapter 5, Survey and Mapping.** Chapter Five encompasses all of the information regarding surveys and mapping. The Survey Unit provides information on the field

survey, property, utility locations and related data. The data collected provides topographic maps, site maps, right-of-way and utility plats and base information for developing the design.

5. **Chapter 6, Geotechnical.** Chapter Six provides a discussion on the geotechnical information necessary in highway design. The Geotechnical Unit provides subsurface data and recommendations for earthwork slopes, materials and pavement structure design. When applicable the report includes foundation design for bridges, retaining walls and other structures, along with landslides and subsurface water information.

6. **Chapter 7, Hydrology/Hydraulics.** Chapter Seven provides the necessary information on the hydrology/hydraulic data needed in highway design. The Hydraulics Unit provides runoff data for roadside drainage design. This Unit also provides data to the Structural Unit (for major structures) and designs major hydraulic structures and special water resource features.

7. **Chapter 10, Structural Design.** Chapter Ten provides the necessary information on structural design for highways. The Structural Unit designs bridges, major retaining structures and special structural elements. The Unit will provide complete structural plans, proposed specifications and an estimate of cost for incorporation into the PS&E package.

9.1.2 Design Standards

Guidelines for geometric design have changed significantly over the years. Today's emphasis is on balancing the factors of safety, economy, environmental concerns, energy conservation and social effects with the traditional concerns for volume and speed. Achieving an appropriate balance of the needs of the transportation facility users with values of the environment and communities that are affected involves seeking Context Sensitive Solutions (CSS) and applying innovative decision-making approaches to the project development, design and delivery process.

FHWA has adopted policies and standards for Federal-aid highway design that recognize all of these precepts. They are listed in 23 CFR 625 and supplemented in the *Federal-aid Policy Guide* (*FAPG*). These standards basically adopt AASHTO policy and are applicable to Federal Lands Highway design.

Other Federal agencies, States and many local highway agencies have adopted standards implementing AASHTO policy with supplemental and clarifying criteria.

See Exhibit 9.1-A for a list of the principle FLH programs and corresponding design standards. The appropriate standards are normally identified in the planning, programming or conceptual studies document for the project. Occasionally the designer will need to determine which standards are approved for use on a specific project. The appropriate Unit Chief should be consulted.

The design criteria shown in Exhibit 9.1-A represent both desirable and minimum standards. Each design should be evaluated on the basis of desirable design criteria for the safest overall design.

Cost, social and environmental factors often require standards that are less than desirable. This is particularly true for RRR projects. When these factors dictate design elements resulting in less than minimum standards, the designer must evaluate the consequences and document the decision in accordance with Section 9.1.2.2.

Type of Roadway	Applicable Standards
Forest Highway and Public Lands Highways	23 CFR 625 and FHWA approved State or local standards.
National Park Roads and Parkways	*NPS Standards* (1984) and 23 CFR 625.
Indian Reservation Roads	25 CFR 170, *BIA Design Manual* and 23 CFR 625.
FAA Roads	23 CFR 625.
BLM Access Roads	*FAPG* G6090.13 and *BLM Manual*, Section 9113 – Roads.
Defense Access Roads	23 CFR 625 or FHWA-approved State or local standards.
FS Roads and Trails	*FS Handbook* (FSH 7709.11).
ERFO	Standards determined by classification of highway to be repaired or reconstructed. (See *EFRO Manual*).
Refuge Roads	23 CFR 625 as applicable to RRR projects.

Note: *Where there is a conflict between agency standards and 23 CFR 625, the design criteria should be mutually resolved with the client agency.*

Exhibit 9.1-A DESIGN STANDARDS

9.1.2.1 Policy

It is Federal Lands Highway Office (FLHO) policy to use approved standards for the design of projects funded from the highway trust fund. For projects funded through owner-agency appropriations, the owner-agency's standards apply, provided they are consistent with good engineering practice.

9.1.2.1.1 Design Criteria

AASHTO's *A Policy on Geometric Design of Highways and Streets (Green Book)* is the principle source for highway design criteria. Supplements to the *Green Book* include other AASHTO and technical publications adopted as acceptable criteria and other Federal, State and local specifications for use on their roads. These acceptable supplements are referenced throughout this *Manual*.

9.1.2.1.2 Design Speed

A principle element in establishing design criteria is the selection of the design speed for the facility. The design speed should be consistent with the speed the driver expects. It should be logical for the topography, adjacent land use and type of highway. The design speed must equal or exceed the posted or regulatory speed limit of the completed facility. The *Green Book* explains the philosophy of design speed. In most instances, the owner agency has the authority to establish the posted speed for the facility. When necessary, regulatory limits should be recommended to the owner agency to provide guidance in setting posted speeds that are consistent with the design of the highway. However, when system-wide statutory speed limits prevail, they mandate the posted speed.

9.1.2.1.3 RRR Projects

The design policy for RRR projects is the same as new construction unless a separate FHWA-approved State or local RRR design policy is applicable to the project; however, designing these projects to approved standards may not always be possible. Alternative actions should be analyzed where environmental concerns, social impacts, extraordinary costs or limited funds prevent construction to full standards. Analysis should include consideration of adjacent highway sections and the relationship to future improvements, as well as existing conditions and operational and safety conditions that will result from completion of the project. When the analysis concludes that approved standards are not practical, the designer must document each exception to the standards as outlined in Section 9.1.2.2. The design exception analysis and documentation must include into the design any existing substandard conditions that are not reconstructed to current standards as part of the project.

9.1.2.2 Design Exceptions

When approved standards are not obtained, the designer must document all exceptions. There are thirteen principle design elements that are considered controlling criteria and which require documentation each time they are unobtainable:

- design speed,
- lane width,
- shoulder width,
- bridge width,
- structural capacity,
- horizontal curvature,
- vertical curvature,
- gradient,
- stopping sight distance,
- cross slopes,
- superelevation,
- horizontal clearance to structures (tunnels and bridge underpasses), and
- vertical clearance.

In addition to these controlling criteria, the designer should document other elements of operational efficiency or safety that do not meet the standards. Form 9.1-A presents a sample format for documenting design exceptions on a project.

This documentation supporting the design exception decision should be prepared at the earliest possible point in the design process and must become a part of the PS&E package presented to the owner agency.

Documentation of design exceptions should include an explanation of the conditions prohibiting full standards, the operational and safety effects of the design exception and a description of the mitigating measures proposed to maximize operation and safety of the facility.

9.1.2.3 Mitigating Design Exceptions

Tort liability is a major concern of the government. The designer must ensure that the design process is in compliance with all applicable standards, and that decisions regarding design exceptions are properly documented.

The exception to standards outlined in *FLHM* 3-C-2 permits the Division Engineer to vary the controlling criteria when alternatives merit precedence over standards.

The project plans should include mitigation (e.g., curve signs, turn signs, advisory speed plates, positive guidance, appropriate roadside design features) when a curve design is an exception to the standard for the posted or regulatory speed limit. The *MUTCD* specifies installation of advisory speed plates following a determination of the safe speed by an engineering study.

Federal Highway Administration
Federal Lands Highway Divisions

Design Standards Information

Project Number: _____

Project Name: _____

Description/Termini: _____

_____

☐ New Construction ☐ Reconstruction ☐ RRR

Highway System: _____

Owner Agency: _____

Functional Classification: _____

Traffic Data:

	ADT			Percent Trucks		
Year	Average	Seasonal	DHV	DHV	ADT	D
Current						
Future						

Design Speed: _____ Terrain: ☐ Level ☐ Rolling ☐ Mountainous

Applicable Standards: _____

_____

Design Criteria:	Standard	As Designed	Exception
Horizontal Curvature			
Superelevation			
Superelevation Runoff			
Crown			
Gradient			
Travel Way Width			
Shoulder Width			
Vertical Curvature			
Stopping Sight Distance			
Bridge Width			
Bridge Railing			
Clear Zones			

Form 9.1-A SAMPLE DOCUMENTATION OF HIGHWAY DESIGN STANDARDS

Description of and reasons for exceptions to standards: _____

Analysis of risks and design considerations proposed to mitigate exceptions: _____

Approval

☐ There are no exceptions to applicable standards.

☐ The exceptions noted have been reviewed with client or cooperating agencies and are considered acceptable.

Date	Design Engineer
Date	Design Project Manager

Approval is recommended

Date	Project Development Engineer

Approved for final PS&E

Date	Division Engineer

Form 9.1-A SAMPLE DOCUMENTATION OF HIGHWAY DESIGN STANDARDS
(Continued)

If engineering data is not available, a field method of measuring speed for horizontal curvature uses a slope meter, more commonly referred to as the ball bank indicator. When advisory speed plates are warranted, the project engineer should be provided with a listing of curve signs, turn signs and advisory speed plates needed for the project as determined by theoretical design speed criteria. Signing normally appears on the plans but occasionally supplemental studies dictate the need to forward additional data to the field.

The project engineer can contact the jurisdictional agency traffic engineer to arrange for a curve speed determination. See the *Green Book* for a discussion on the relationship of ball bank readings and curve speeds.

Exhibit 9.1-B establishes minimum signing requirements for curves and turns.

Some agencies have criteria other than what is shown in Exhibit 9.1-B. The designer should check the agencies' standards for conflicts between the two and use the more conservative signing criteria.

Determining the appropriate standards to be used for roadway lane and shoulder widths is sometimes difficult. In some cases, the project may be the only improvement on a route for many years. In other cases, the maintaining authority may have a policy that only resurfacing projects will be applicable to a route to use available funding for higher priority transportation facilities. In these instances, the compatibility with adjacent sections of the highway may be the governing criteria. When compatibility with adjoining roads is the controlling factor, a design exception is appropriate to establish the specific design criteria for the RRR project.

Extraordinary cost or adverse environmental impacts could also result in design exceptions. When the highway operating agency's approved transportation plan specifies less than the standard widths for a route, this width requires documentation as a design exception.

The remaining controlling criteria are usually limited to site-specific locations. The designer must mitigate these design exceptions through the normal design process.

Some RRR projects cannot be surveyed cost effectively in enough detail to identify many of the exceptions to the controlling criteria (e.g., superelevation, grades). These projects place considerable emphasis on the awareness and engineering judgment of the designer. Any on-site study or field review for RRR projects should document any identifiable exceptions to standards and design policy.

9.1.3 Computer-Aided Design and Drafting (CADD)

Information on Computer-Aided Design and Drafting is included in Section 9.7.

Posted Speed (km/h)	Curve Speed[2] (km/h)								
	≤ 30	40	50	55	60	70	80	90	100
100	TA	TA	TA	CA	CA	CA	C	C	
90	TA	TA	TA	CA	CA	C	C		
80	TA	TA	TA	CA	C	C			
70	TA	TA	TA	C	C				
60	TA	TA	T	C					
55	TA	T	T						
50	T	T							
40	T								
30									

Posted Speed (mph)	Curve Speed[2] (mph)								
	≤ 20	25	30	35	40	45	50	55	60
60	TA	TA	TA	CA	CA	CA	C	C	
55	TA	TA	TA	CA	CA	C	C		
50	TA	TA	TA	CA	C	C			
45	TA	TA	TA	C	C				
40	TA	TA	T	C					
35	TA	T	T						
30	T	T							
25	T								
≤ 20									

Notes:

1. See MUTCD (Section 2C.06 and 2C.07).

2. Determine the curve speed by use of the ball bank indicator.

Key:

A = Advisory Speed Plate
C = Curve Warning Sign, Reverse Curve Sign (or Winding Road Sign)
T = Turn Sign, Reverse Turn Sign (or Winding Road Sign)

Exhibit 9.1-B MINIMUM SIGNING[1] FOR CURVES AND TURNS

9.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all-inclusive, the publications listed will provide the designer with additional information to supplement this *Manual*.

1. *A Policy on Geometric Design of Highways and Streets,* AASHTO, current ed.

2. *Highway Capacity Manual,* TRB Special Report No. 209, Transportation Research Board, current ed.

3. *Manual on Uniform Traffic Control Devices (MUTCD)*, FHWA, current ed.

4. *Traffic Control Devices Handbook,* ITE, current ed.

5. *Park Road Standards*, US Department of the Interior, National Park Service, 1984.

6. *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP- XX)*, FHWA, current ed.

7. *Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals*, AASHTO, current ed.

8. *Guide for Development of Bicycle Facilities*, AASHTO, 1991.

9. *Railroad-Highway Grade Crossing Handbook*, Report No. FHWA-TS-86-215, 1986.

10. *Intersection Channelization Design Guide*, NCHRP 279.

11. *An Informational Guide for Roadway Lighting*, AASHTO, 1984.

12. *A Guide of Accommodating Utilities Within Highway Right-of-Way*, AASHTO, 1994.

13. *Roadway Lighting Handbook*, FHWA, 1978 (and addendum 1983).

14. *Americans with Disabilities Act Accessibility Guidelines (ADAAG)*, Architectural and Transportation Barriers Compliance Board, current ed.

15. *Roadside Design Guide*, AASHTO, current ed.

16. Recommended Procedures for the Safety Performance Evaluation of Highway Features, NCHRP Report 350, TRB, 1993.

17. *Design Risk Analysis* (Volume I and II), FHWA-FLP-91-001, FHWA, 1991.

18. *Standard Practice for Use of the International System of Units (SI)*, The Modernized Metric System, E380-93, ASTM, 1993.

19. *Trail Design Manual, "Trails for the Twenty-First Century," Planning, Design, and Management Manual for Multi-use Trails*, Rails to Trails Conservancy, 1993.

20. *Designing Safer Roads*, TRB Special Report No. 214, Transportation Research Board, 1987.

21. *Horizontal Alignment Design Consistency for Rural Two-Lane Highways*, FHWA-RD-94-034, FHWA, 1995.

22. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*, FHWA-RD-99-207, FHWA, 2000.

23. *A Guide for Achieving Flexibility in Highway Design*, AASHTO, 2004.

24. *Interactive Highway Safety Design Model*, FHWA, current ed.

25. *Guide for the Planning, Design and Operation of Pedestrian Facilities,* AASHTO, 2004.

26. *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT<400)*, AASHTO, 2001.

9.3 INFORMATION GATHERING

See Chapter 4 for information on scoping, background data, preliminary design standards and mitigating measures before beginning detailed design activities.

9.3.1 Design Study

A design study documents considerations and conclusions reached during the development of a project. Although it may not always result in a formal document, the study provides a history of the project from start to completion of the PS&E.

When the designer has completed the PS&E, the following applicable data should be available in the files:

- A project description that, at a minimum, includes the following:
  - description of existing conditions,
  - comparison of proposed work with "no build" alternative,
  - extent of selection and examination of alternatives,
  - identification of deficiencies with costs to correct, and
  - design parameters used.
- Evaluation of any substantial change in commitments made in the environmental document.
- Documentation regarding hearings advertised, held or required.
- Cost estimates including applicable right-of-way acquisition, utility relocation, permits, project costs, construction engineering, incentive/disincentive clauses and project agreements.
- Access control requirements.
- Reasons for deviations from adopted policy and standards.
- The following traffic data elements:
  - present and design year average daily traffic (ADT) and seasonal average daily traffic (SADT), when applicable, with percentage of (S)ADT used for design hour volume (DHV), for directional split (D) and for trucks (T);
  - DHV for two-lane, two-way highways, crossroads and frontage roads; and
  - turning movements.
- The following special traffic data elements:

  - noise impact studies;
  - signal warrants;
  - air quality studies;
  - illumination warrants;
  - left turning movements;
  - temporary traffic control plans; and
  - other studies, as required.

- Crash history.
- Geotechnical and materials engineers' reports.
- Involvements on railroad right-of-way (e.g., crossings, encroachments).
- Utility involvements.
- Permit requirements or agreements.
- Roadway sections, including all new or widened bridges.
- Pavement structure section.
- Drainage consisting of hydraulic concepts, floodplain studies, culvert selection, etc.
- Erosion control.
- Illumination.
- Fencing.
- Signing and marking.
- Signalization.
- Roadside safety features, barriers, impact attenuators, etc.
- Roadside development (e.g., landscaping, aesthetic treatments).
- Other permanent traffic control in terms of delineation.
- Temporary traffic control plans through construction.
- Bicycle and pedestrian considerations.
- Related data affecting the ultimate construction and operation of the facility (e.g., right-of-way considerations).

9.3.2 Surveying and Mapping

Chapter 5 covers the surveying and mapping information that the designer can expect to receive. Ideally the design, survey, geotechnical and conceptual study engineers, and the owner agency review the proposed work on the ground and determine the information and limits of the survey required to complete the project.

When field reviews are not possible, it is still beneficial for the designer and survey and mapping engineer to discuss the field information required. In many cases, the designer's experience with new construction, reconstruction and RRR projects can increase the effectiveness of the survey crew.

At some point in the project development process, the designer usually provides the appropriate survey unit with the information to stake the project in the field. This could include notes to establish centerline, set slope stakes, clearing limits, reference points, right-of-way and other control points necessary to complete the work. The designer must keep the design files purged so the information provided for the stakeouts is current, correct and reflects the design criteria established for the project. All notes prepared for field use will require confirmation to prevent the possibility of providing incorrect data.

9.3.3 Crash Data

On all projects the crash history should be analyzed. In addition, potentially hazardous features and locations should be identified to determine appropriate safety enhancement. A crash study by location, type, severity, contributing circumstances, environmental conditions and time periods may suggest possible safety deficiencies. The designer should refer to Chapter Eight for details on data collection, crash investigation and analysis. Refer to Chapter Four for details on obtaining other necessary crash data.

9.3.4 Existing Plans

An excellent source of information for reconstruction and RRR projects is as-constructed plans. Each Federal Lands Highway Division office has access to a set of as-constructed plans for its completed projects. They contain information on alignments, drainage, bridges, right-of-way, pavement structure and other engineering features.

Local government and other Federal agencies can also provide as-constructed plans and a variety of information relating to a specific section of highway. The NPS maintains microfilm files on as-constructed plans.

The designer should contact the utility company first to determine the project's effect on utilities. The utilities typically are on the right-of-way by permit from the highway operating agency.

While information from as-constructed plans and from other agencies has significant value, the data should not be blindly accepted as fact. Field verification is necessary.

9.3.5 Agency Contacts

The designer will usually find that the primary agency contacts were established during the environmental and conceptual studies phases of the project by environmental and conceptual-design personnel.

The designer needs to continue to coordinate with these agency contacts to achieve a smooth transition between the design and construction phases.

The SEE study team membership comprises the principle agency contacts for projects that require an EIS or FONSI. On projects with a CE, the designer may initiate contact with other agencies regarding permit requirements and clearances.

The FHWA Federal-aid Division office may participate in the development of the project. The extent of the involvement varies from office-to-office, but using the expertise available in the FHWA Federal-aid Division offices provides an independent review of the design.

On National Park Service projects, the coordinator in the Denver Service Center, or if appropriate, the National Park Service Support Office or the local Park representative is the principal contact for input and review of the design alternatives. The NPS is responsible for coordination with other agencies and outside disciplines when applicable.

When using other agency funds, the project agreement should address the principle contacts and responsibilities for coordination.

The interagency interdisciplinary approach to design is fundamental to obtaining an end product that will serve the public and be consistent with Federal, State and local goals, objectives and standards.

Early contact and coordination with cooperating agencies ensures an end product with minimum conflict and controversy.